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Differences in Sensation Level between the Widex SoundTracker and Two Real-Ear Analyzers

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Abstract

Background: SoundTracker is an algorithm in Widex's Compass fitting software that could potentially be used to estimate a patient's aided sensation level (SL). SoundTracker's accuracy of estimating a patient's SL has never been verified in comparison to SL measured with commercially available real-ear analyzers.

Purpose: Determine whether statistically significant differences are present between the estimated SL of the Widex SoundTracker software application and the measured SL of the Audioscan Verifit and Frye 6500 real-ear analyzers at 500, 1000, 2000, and 4000 Hz.

Research Design: This study used a randomized repeated measures design to determine differences in SL between SoundTracker and the Verifit and 6500.

Study Sample: Ten subjects (N = 20 ears) were recruited who were experienced users of behind-the-ear hearing aids with conventional vented earmolds and had bilateral sensorineural hearing loss that was >30 dB HL below 1000 Hz and ≤70 dB HL to 4000 Hz.

Data Collection and Analysis: Real-ear in-situ thresholds (dB sound pressure level [SPL]) and real-ear aided responses (REAR; dB SPL) were measured at 500, 1000, 2000, and 4000 Hz to determine differences in SL between SoundTracker, Verifit, and 6500. A three-factor repeated measures analysis of variance (ANOVA) was utilized to determine differences between method (real-ear analyzers and SoundTracker), analyzer (Verifit and 6500), and frequency (500, 1000, 2000, and 4000 Hz).

Results: Mean differences in measured SL for the Verifit and 6500 were ≤2 dB when compared to the estimated SL using SoundTracker. A statistically significant difference in SL was present between the Verifit and SoundTracker at 2000 Hz ($p < 0.01$), but no significant differences were present at 500, 1000, and 4000 Hz. A statistically significant difference in SL was present between the 6500 and SoundTracker at 4000 Hz ($p < 0.01$), but no significant differences were present at 500, 1000, and 2000 Hz. Mean differences in measured SL between the real-ear analyzers (difference of SoundTracker SL minus Verifit SL compared to the difference of SoundTracker SL minus 6500 SL) were ≤2 dB with a statistically significant difference present at 2000 Hz ($p < 0.01$), but no statistically significant differences were present at 500, 1000, or 4000 Hz.

Conclusions: Nearly 85% of the differences between the estimated SoundTracker SL and the measured SLs of the Verifit and 6500 were ≤2 dB. Despite some limitations of this study, SoundTracker could be useful as a counseling tool to illustrate to patients which sounds are audible or inaudible when unaided and aided.

Key Words: Hearing aid, in-situ threshold, live speech mapping, real-ear measures, sensation level, SoundTracker

Abbreviations: AISA = Assessment of In-Situ Acoustics; ANSI = American National Standards Institute; LSM = live speech mapping; ORCA = Office of Research in Clinical Amplification; REAR = real-ear aided response; RECD = real-ear to coupler difference; REUG = real-ear unaided gain; REUR = real-ear unaided response; RMS = root mean square; SL = sensation level; SPL = sound pressure level

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Real-ear live speech mapping (LSM) (also referred to as sound pressure level [SPL] testing, visible speech, and so on) is a verification procedure using real-ear measures to illustrate the relationship between amplified speech and a patient's hearing thresholds and uncomfortable loudness levels. LSM has been described as having several uses including being a useful counseling tool during the hearing aid evaluation and fitting process (Ross and Smith, 2005; Krishnamurti, 2006; Moore, 2006; Beck and Duffy, 2007). A typical sound source used during LSM is "live speech" from the audiologist and/or the patient's family members. Using LSM allows the patient and family to "see" whether the spectrum of speech is audible or inaudible when a patient is unaided and/or wearing a hearing aid. The patient and family can then observe the benefits received from amplification because speech is amplified above the patient's threshold. Particularly, the patient and family members can observe the patient's sensation level (SL) or the amount of amplification above the patient's threshold to show how much benefit the patient receives with hearing aids. LSM is available in most real-ear analyzers; however, Widex USA Inc. provides a fitting utility called SoundTracker within the Compass fitting software that is similar to LSM.

SoundTracker is Widex's software algorithm that, in essence, is a sound level meter that measures the input of a signal using the hearing aid's microphones and *estimates* the output from the hearing aid in the patient's ear canal. SoundTracker estimates the output by considering the input level of the signal, the average or individual real-ear to coupler difference (RECD), the Sensogram, and results of the feedback test (Kuk et al, 2004). The Sensogram is used to measure the patient's in-situ hearing thresholds in 4, 10, or 15 frequency regions (depending on the model of hearing aid) by generating pulsed, warble frequency specific tones through the hearing aid with the patient responding when the tone is heard. The results from the Sensogram take into account the acoustic effects of the earmold, such as the residual volume, impedance of the ear, earmold (or receiver) tubing, and venting. The feedback test contributes to the predicted output by estimating the "true" vent size (effectiveness of the seal provided by the earmold or hearing aid case and the vent) of the earmold through an algorithm called Assessment of In-Situ Acoustics (AISA).

After the Sensogram and feedback measures are completed, the fine-tuning section of the software displays SoundTracker. The SoundTracker screen reports the unaided, aided, and peak output in relation to the patient's in-situ hearing thresholds determined via the Sensogram and predicted uncomfortable loudness levels. The results can be displayed in dB HL or dB SPL. Figure 1 reports the SoundTracker screen, with the lighter lower bars representing the input levels of the unamplified signal in each of the frequency channels, and the darker bars sitting on top of the unaided bars represent the instantaneous gain provided to that channel. The height of the bar represents the amplified or aided output. The connected dashed line above these bars is the instantaneous peak output of the hearing aid as measured in the average ear canal (or individual ear canal if individual RECD is provided); the solid lower curve represents that patient's in-situ thresholds; and the solid upper curve represents the predicted uncomfortable loudness levels.

As can be seen in Figure 1, SoundTracker could be used to measure the input of various signals using the hearing aid microphones to estimate the SL of those signals by comparing the input level and/or aided output relative to the patient's in-situ thresholds. According to Kuk (2012), "while one cannot expect a direct correspondence in output level between SoundTracker and a real-ear analyzer (because of the difference in output between a 711 coupler and the individual ear-canal), one can expect a direct correspondence in" the SL "between the Sensogram and the SoundTracker output, and the SL between the Sensogram and the real-ear measurement output" (p. 30). The major reason is because the estimated output of SoundTracker "and the Sensogram were determined using the 711 coupler; while in real-ear measurement" both the hearing aid output and the in-situ thresholds were determined "using the individual's ear canal as the cavity/coupler" (Kuk, 2012, p. 30). As such, the difference between threshold and output, or the "SL, measured with the SoundTracker and real-ear measurement should be similar" (Kuk, 2012, p. 30).

Currently, no peer-reviewed studies have verified the accuracy of the estimated SL of SoundTracker. The gold standard for accurately measuring hearing aid output is real-ear measures (Valente et al, 2006). Real-ear analyzers utilize a probe microphone placed in the ear canal to directly measure the output of the hearing aid near the tympanic membrane. While real-ear measures are the gold standard for verification of hearing aid performance, not all audiologists routinely use real-ear measures, and an unknown number either have a real-ear analyzer but do not use it or do not have real-ear analyzers and, therefore, do not have the option of using LSM as a counseling tool. SoundTracker, however, could potentially be used with hearing aids manufactured by Widex as a LSM *counseling* tool if the results of using SoundTracker are found to be an accurate estimate of SL.

The primary purpose of this study, therefore, was to determine whether statistically significant differences exist between the estimated SLs from SoundTracker and the measured SLs from two real-ear analyzers (Audioscan Verifit and Frye 6500) at 500, 1000, 2000, and 4000 Hz. A secondary purpose was to determine whether statistically significant differences exist in measured SL differences between the Verifit and 6500 at the same test frequencies.

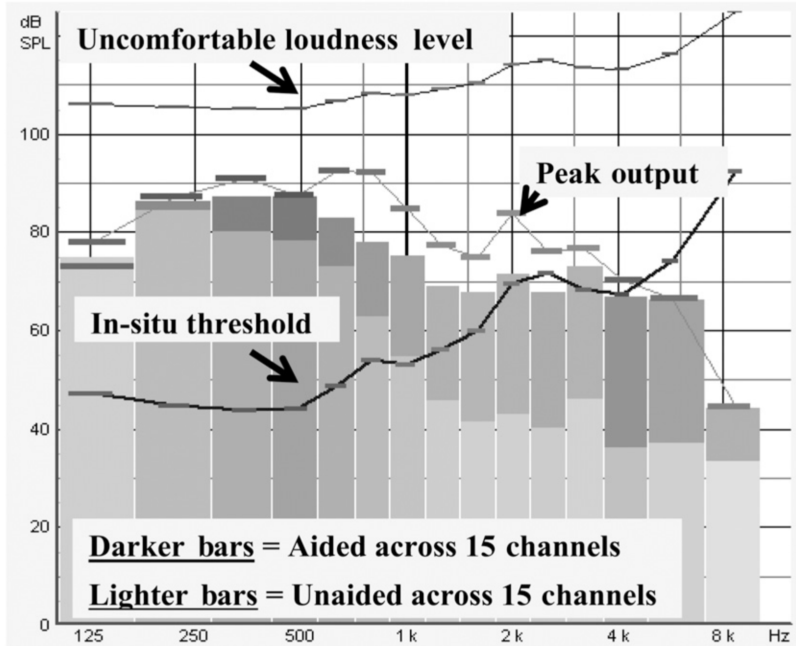

Figure 1. SoundTracker screenshot reporting in-situ hearing thresholds *(lower curve),* predicted uncomfortable loudness levels *(upper curve),* the unaided output *(light shaded bars),* gain *(dark shaded bars),* and peak output *(middle dashed curve)* for 15 channels in dB SPL. Note: Average output can also be displayed.

METHODS

Subjects

An a priori power analysis using pilot data completed at Widex USA's Office of Research in Clinical Amplification (ORCA) determined that 10 ears would be required based on a two-tailed test, an alpha of 0.05, and power of 0.80. Ten subjects (20 ears), however, were recruited from Washington University in St. Louis School of Medicine. Inclusion criteria included: (a) adults 18 yr of age or older, (b) current users of bilateral behind-the-ear hearing aids with a conventional vented earmold, and (c) patients with a sensorineural hearing loss >30 dB HL below 1000 Hz and ≤70 dB HL to 4000 Hz (rationale for these hearing thresholds will be discussed later). Subjects were excluded if they did not meet the above criteria and could not commit to the time requirements of the study. All subjects reviewed and signed the informed consent approved by the Human Research Protection Office before entering the study.

Seven females and three males were recruited with a mean age of 80.3 yr (SD = 7.9 yr). Mean pure-tone air conduction thresholds for the right and left ears are reported in Figure 2.

Equipment

A pair of Widex Clear 440 C4-9 hearing aids were used for each test session, and subjects used their current earmolds (mean vent size of 2.5 mm [SD = 0.7 mm]). To verify that the pulsed, warble pure-tones generated for the Sensogram were calibrated at each test frequency prior to the study, a linearity check of the Sensogram was completed by Widex USA's ORCA to ensure each hearing aid was calibrated prior to initial testing. Each hearing aid was connected to a 2 cc coupler that was attached to a pressure microphone of a Quest 1800 Precision sound level meter, and the output was measured using an input level of 25, 50, and 75 dB SPL of the Sensogram tones at 500, 1000, 2000, and 4000 Hz. The output level obtained at an input of 25 dB SPL was subtracted from the output level measured using an input level of 50 dB SPL, and the input level of 50 dB SPL was subtracted from the output level measured using an input level of 75 dB SPL to determine level differences. All measures were within ±1 dB of the expected 25 dB SPL difference. Prior to each test session, the hearing aids were dehumidified, placed into test mode (full-on gain), and tested electroacoustically to ensure the hearing aids were working according to the manufacturer's specifications.

The Audioscan Verifit (software version 3.4.26) and Frye 6500CX (software version 4.8) were utilized in this study. To ensure the real-ear analyzers were operating properly, the Verifit and 6500 real-ear analyzer reference and probe microphones and loudspeakers were calibrated prior to the beginning of the study. The Verifit and 6500 reference and probe microphones were also leveled for each subject using the proper methodology

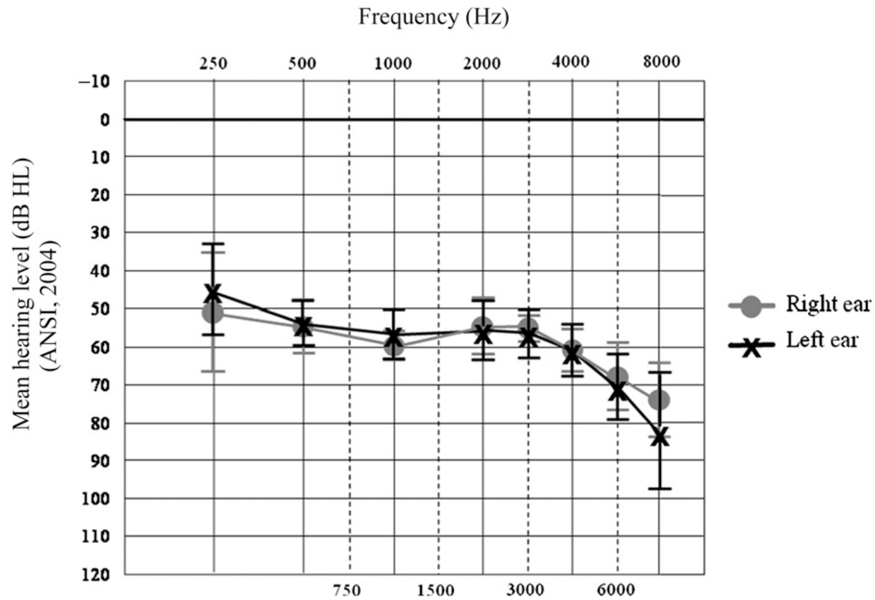

Figure 2. Mean (±1 SD) pure-tone air conduction thresholds for the right and left ears for the 10 subjects.

suggested by the manufacturer of the real-ear analyzer (Frye Electronics Inc., 2005; Etymonic Design Inc., 2007, 2007b).

Procedures

Prior to testing, otoscopy was performed to ensure both ear canals were clear of cerumen and debris. Pure-tone air conduction thresholds from 250 to 8000 Hz were measured in octave and midoctave steps in each ear using a GSI-61 audiometer calibrated to the American National Standards Institute (ANSI) S3.21-2004 standard (ANSI, 2004) and using TDH-50 MX-41/AR supra-aural headphones. The resulting audiogram was entered into NOAH version 4. Next, a probe tube connected to the probe microphone of the 6500 was placed into the subject's right or left ear canal, the reference microphone was placed over the test ear, and the loudspeaker was leveled. Then, the real-ear unaided gain (REUG) was measured using speech-weighted composite noise presented at 65 dB SPL, and the probe tube was advanced further into the ear canal, if necessary, until 0 dB of gain was measured at 6000 Hz to ensure the probe tube was within 5 mm of the tympanic membrane (Baum and Valente, 2009). At this point, the probe tube was marked at the intertragal notch with a marker. The Verifit probe tube was then placed adjacent to the 6500 probe tube for the respective ear and was marked at the same length based on the previous REUG measure.

A new #13 battery was placed in each Clear 440-9 hearing aid, and the subject's earmolds were cleaned and then connected to the hearing aids. The hearing aids were wirelessly connected to the Widex Compass software with a USB Link, and the data from Compass was used to ensure initial programming based on the subject's audiogram. The hearing aids were programmed in the Compass software with the following parameters: classic flex earmold (conventional earmold), binaural fit, AISA turned on, using average RECD values, and the measured vent size of the earmold. The microphone was programmed as omnidirectional, with noise reduction and Sound Softener turned off.

The hearing aid and earmold were placed onto the subject's ear with the probe inserted into the vent of the earmold until the mark was at the intertragal notch and it was secured with tape. Next, a Sensogram was performed at 500, 1000, 2000, and 4000 Hz (if greater than a 20 dB difference was noted between frequencies, the frequencies in between were also measured). This was followed by completing a feedback test to ensure the appropriate amount of Maximum Stable Gain and determine the effective vent diameter through AISA. Next, the simulated aided soundfield thresholds were examined in the Compass software to determine whether the simulated aided soundfield threshold for each test frequency was close to 20 dB HL. If not, the gain was adjusted in the specific frequency channel to arrive as close to the 20 dB HL simulated aided soundfield threshold target as possible (Kuk et al, 2003). Next, real-ear in-situ threshold measures at 500, 1000, 2000, and 4000 Hz using the Sensogram and the two real-ear analyzers were completed in a randomized order.

REAL-EAR IN-SITU THRESHOLD MEASURES

The respective real-ear analyzer was placed into the LSM mode for the Verifit or SPL Testing mode for the 6500. The reference microphone and noise reduction were disabled for the 6500 but could not be disabled on the Verifit. The microphones on the hearing aids were muted automatically when placed in the Sensogram mode, and the real-ear analyzer was used to measure the level of the Sensogram in-situ thresholds at 500, 1000, 2000, and 4000 Hz in the subject's ear canal. First, the 500 Hz signal was presented and the measured SPL on the monitor of the real-ear analyzer was frozen (Verifit) or closely examined (6500) after the last presentation of the signal to determine the peak output of the pulsed, warble pure-tone signal generated via the Sensogram. Each test frequency was measured in dB SPL using the Verifit and 6500 (Figs. 3A–B). For example, in Figure 3A, the measured peak output for a measured in-situ threshold at 1000 Hz was 60.5 dB SPL for the Verifit and in Figure 3B 69.0 dB SPL for the 6500. Interestingly, the measured peak output was not always at the test frequency. For example, in Figure 3A the Verifit measure was slightly above 1000 Hz and as seen in Figure 3B, the 6500 measure was slightly below 1000 Hz. The order of ear (right or left) and analyzer (Verifit or 6500) was randomized, but the order of frequency was always 500 Hz, followed by 1000, 2000, and 4000 Hz. Each measure at each frequency was completed three times and averaged. Note that from this point on, when the terms *estimated* or *measured SL* are used, it represents the average of three measures at each test frequency. Upon completion of in-situ threshold measures, real-ear aided response (REAR) measurements were completed. Note that the real-ear analyzer that was utilized first for in-situ threshold measures was also used to complete REAR measures before completing the in-situ thresholds with the second real-ear analyzer to prevent variability caused by probe tube movement/placement.

REAL-EAR AIDED RESPONSE MEASURES

The earmolds with the respective probe tubes of the real-ear analyzer were kept in the same position in the subject's ear for the subsequent REAR measures. The SoundTracker screen was accessed via Compass to make the estimated REAR measures for SoundTracker, and all REAR measures were completed in dB SPL. A pink noise stimulus was presented at 65 dB SPL when measures were completed using the Verifit, and a speech-weighted composite noise presented at 65 dB SPL was used when measures were completed using the 6500. The reference microphone was activated, but noise reduction remained off for the 6500. The loudspeaker for each real-ear analyzer was placed at 0°, and a ruler ensured that the center of the subject's head was always the same distance from the loudspeaker for the Verifit and 6500 (used the distance the reference microphone was leveled for each particular subject). This measurement was made prior to each test measure to minimize head movement. The pink noise or speech-weighted composite noise was presented, and the average output mode of SoundTracker was activated. The signal was presented for an initial 4 to 5 sec before

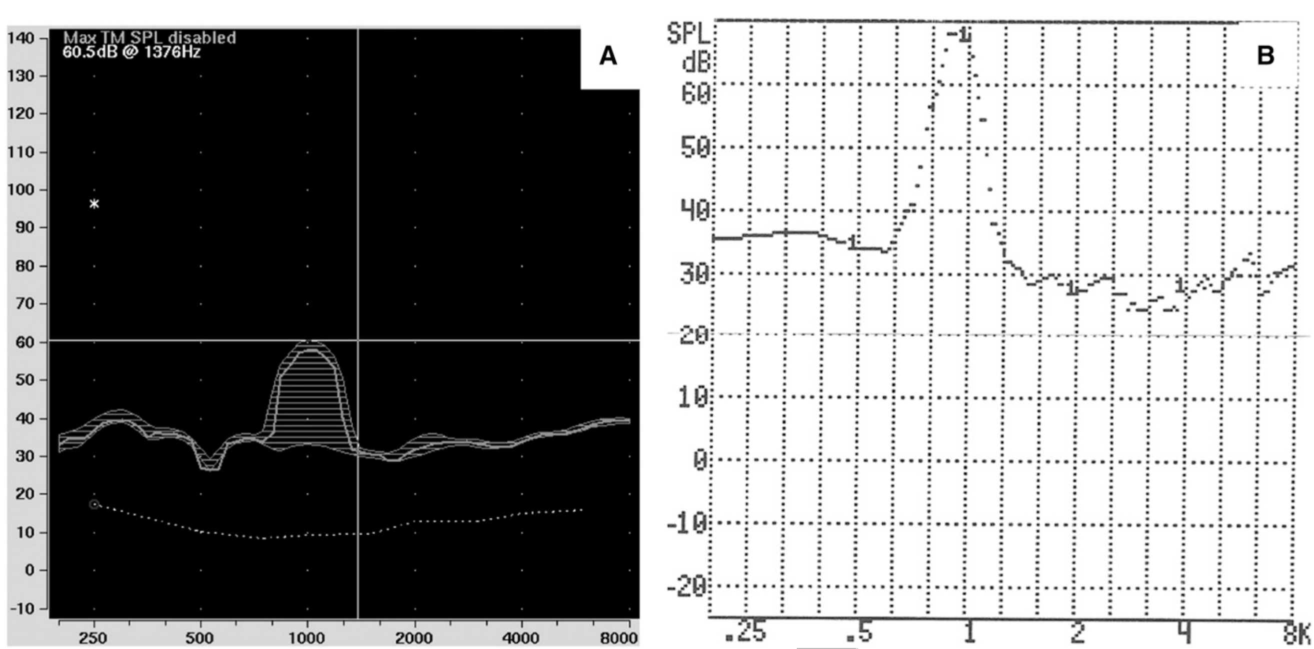

Figure 3. Screenshots of Sensogram in-situ peak output thresholds measured with the Verifit (*A,* 60.5 dB SPL) and 6500 (*B,* 69.0 dB SPL) at 1000 Hz.

averaging began to allow the output of the hearing aid to stabilize to adjustments in gain due to the compression characteristics of the Clear 440 C4-9 hearing aids. The REAR was then averaged over a 10 sec period. After the respective stimulus was presented for 10 sec, the screen was frozen on SoundTracker, and the input signal was turned off. The REAR was measured at each of the four test frequencies. For example, in Figure 4A, the measured REAR at 1000 Hz for the Verifit was 88.0 dB SPL, 80.0 dB SPL for the 6500 (Fig. 4B), and 81.5 dB SPL for the SoundTracker long-term root mean square (RMS) (in Fig. 4C using the Verifit's pink noise signal). The averaged REAR from the real-ear measurement analyzer and long-term RMS from SoundTracker were recorded at 500, 1000, 2000, and 4000 Hz. The test session lasted approximately 2 hr, and each subject received a $50 debit card for participation.

CALCULATING SL

All measures were entered into an Excel spreadsheet, which was created to automatically calculate SL as well as differences in SL between SoundTracker and the two real-ear analyzers. An example of how SL and SL difference was calculated is provided below using the Verifit as an example. The estimated SL using SoundTracker was calculated by subtracting the Sensogram thresholds in dB SPL from the long-term RMS for a 65 dB SPL input signal. For example, in Figure 4C the long-term RMS was 81.5 dB SPL at 1000 Hz, and the Sensogram threshold was 57.0 dB SPL; therefore, the SoundTracker SL was 24.5 dB. The measured SL for the Verifit was calculated by subtracting the peak output of in-situ thresholds from the REAR for a 65 dB SPL signal as measured with the respective real-ear analyzer. For example, using the Verifit in Figure 4A the REAR at 1000 Hz was 88.0 dB SPL, and in Figure 3A the peak output for the in-situ threshold measure at 1000 Hz was 60.5 dB SPL; therefore, the Verifit SL was 27.5 dB.

Finally, the differences in measured SL between the respective real-ear analyzer and SoundTracker were calculated by subtracting the respective real-ear analyzer's SL from the SoundTracker SL. Using the example stated above, the SL difference between SoundTracker and Verifit was 24.5 – 27.5 = −3.0 dB.

RESULTS

A three-factor repeated measures analysis of variance (ANOVA) was performed examining differences between method (real-ear analyzers and SoundTracker), analyzer (Verifit and 6500), and frequency (500, 1000, 2000, and 4000 Hz). Results revealed mean differences for the main effect of method ($F(1, 9) = 9.4$; $p < 0.05$), analyzer ($F(1, 9) = 19.0$; $p < 0.01$), and frequency ($F(3, 27) = 8.3$; $p < 0.001$), the two-factor interaction of analyzer × frequency ($F(3, 27) = 22.9$; $p < 0.001$), and the three-factor interaction of method × analyzer × frequency ($F(3, 27) = 9.3$; $p < 0.001$) were statistically significant.

Differences between SoundTracker and Real-Ear SL

The 160 individually measured differences in SL (10 subjects × 2 ears × 2 real-ear analyzers × 4 test frequencies) are displayed in the bar graphs in Figures 5A–D for each test frequency. The x-axis reports measured SL differences and the y-axis the frequency of occurrence of each SL difference. A negative value indicates greater measured SL for the respective real-ear analyzer compared to the estimated SL for SoundTracker. Mean differences between the estimated SL for SoundTracker

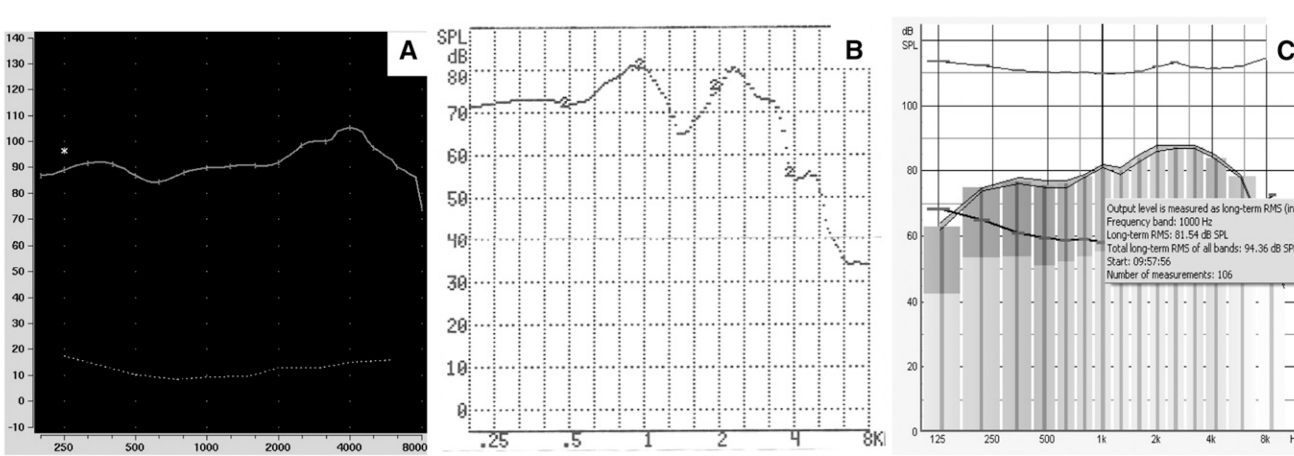

Figure 4. Screenshots of REARs examining the long-term RMS at 1000 Hz measured with the Verifit (65 dB SPL pink noise) (*A,* 88.0 dB SPL) and the 6500 (65 dB SPL speech-weighted composite noise) (*B,* 80.0 dB SPL) and as measured with the respective signal (in this example, pink noise) via SoundTracker (*C,* 81.5 dB SPL).

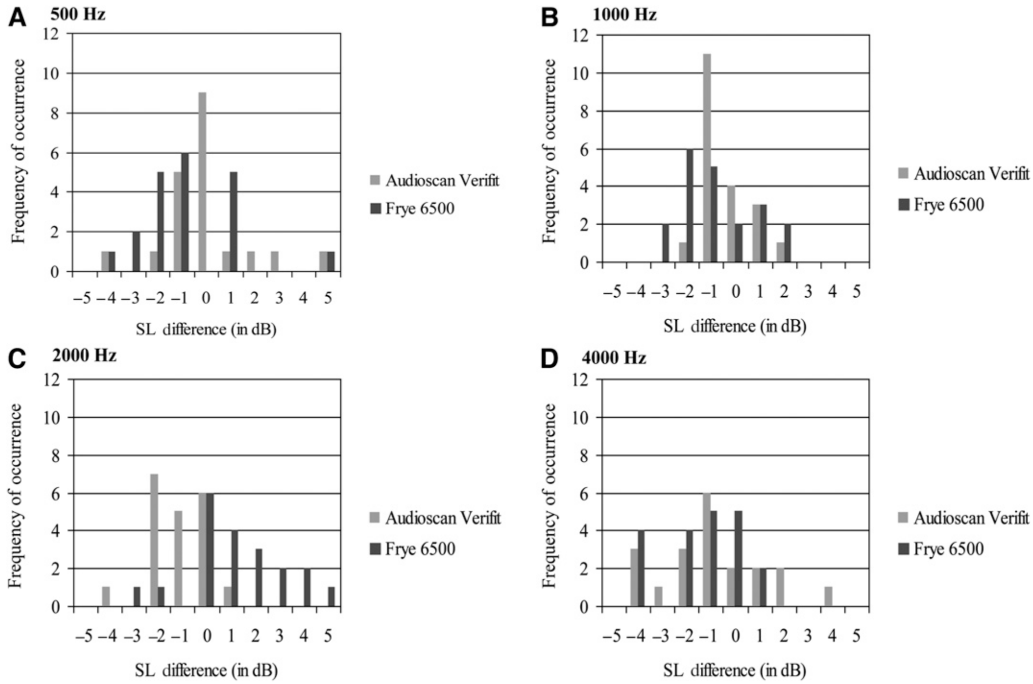

Figure 5. Bar graphs displaying differences between the estimated SL of SoundTracker and the measured SL of the Audioscan Verifit and Frye 6500 at 500 Hz *(A)*, 1000 Hz *(B)*, 2000 Hz *(C)*, and 4000 Hz *(D)*. A negative value indicates greater measured SL for the respective real-ear analyzer compared to SoundTracker.

compared to the measured SL of the Verifit and 6500 were ≤2 dB (Figs. 6 and 7, respectively). Of the 160 individual SL differences between SoundTracker and the two real-ear analyzers in Figures 5A–D, 21.3% of the data points showed a 0 dB difference, 61.3% showed a ≤1 dB difference, 84.4% showed a ≤2 dB difference, 90.0% showed a ≤3 dB difference, 98.1% showed a ≤4 dB difference, and 100% showed a ≤5 dB difference. Pairwise comparisons revealed a statistically significant difference (mean difference of −1.2 dB, indicating greater measured SL for the Verifit) between SoundTracker and Verifit at 2000 Hz ($p < 0.01$) (Fig. 6). No significant differences between the estimated and measured SL for SoundTracker and Verifit were found at 500, 1000, or 4000 Hz. A statistically significant difference (mean difference of −1.4 dB, indicating greater measured SL for the 6500) between Sound Tracker and the 6500 was revealed at 4000 Hz ($p < 0.01$) (Fig. 7). No significant differences between the estimated and measured SL for SoundTracker and the 6500 were found at 500, 1000, or 2000 Hz. A Cohen's d was performed examining differences between SoundTracker and the Verifit and 6500 (Table 1). All effect sizes were small (below 0.4) and were not considered clinically significant.

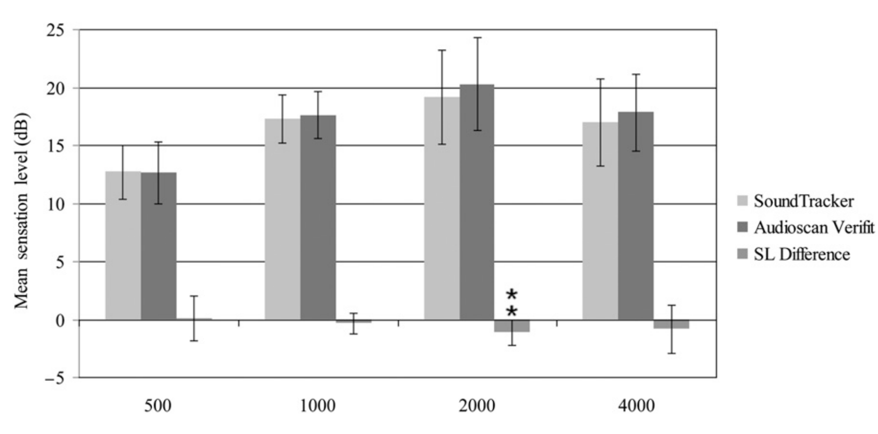

Figure 6. Mean SL (±1 SD) and mean SL difference (±1 SD) for the Verifit compared to SoundTracker at the four test frequencies. A negative SL difference indicates a higher SL for the Verifit compared to SoundTracker. $^{**}p < 0.01$.

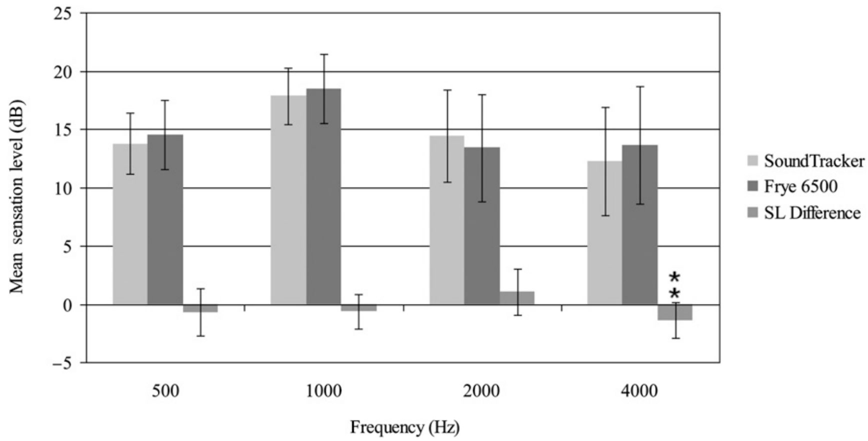

Figure 7. Mean SL (±1 SD) and mean SL difference (±1 SD) for the 6500 compared to SoundTracker at the four test frequencies. A negative SL difference indicates a higher SL for the 6500 compared to SoundTracker. $^{**}p < 0.01$.

Differences between Real-Ear Analyzers

When the above measured SL differences between the Verifit (Verifit SL subtracted from the SoundTracker SL) and 6500 (6500 SL subtracted from the SoundTracker SL) are compared, results were also ≤2 dB (Fig. 8). A pairwise comparison revealed a statistically significant difference between the Verifit and the 6500 (mean difference of 2.2 dB) at 2000 Hz ($p < 0.01$). No significant differences in the measured SL between Verifit and the 6500 were found at 500, 1000, or 4000 Hz.

DISCUSSION

Overall, the mean differences between the estimated SL from SoundTracker and the measured SL from the two real-ear analyzers used in the present study at the four test frequencies were within ≤2 dB. There were, however, statistically significant differences between the estimated SL of SoundTracker and the measured SL of the Verifit at 2000 Hz (mean difference of −1.2 dB) and a statistically significant difference between the estimated SL of SoundTracker and the measured SL of the 6500 at 4000 Hz (mean difference of −1.4 dB). These differences are not clinically significant, however, as the statistically significant differences were <2 dB. The largest SL difference was 5.2 dB, which could be of clinical significance; however, this is likely an outlier as only two measures were ≥5 dB. As mentioned above, of the 160 measured SL differences, 84.4% were ≤2 dB showing close agreement in the estimated and measured SL between SoundTracker and the Verifit and 6500. Overall, differences in the estimated and measured SL between SoundTracker and the Verifit were in better agreement (mean of ≤1.1 dB across frequencies) than SoundTracker and the 6500 (mean of ≤1.4 dB across frequencies), although these differences were small. When these differences in measured SL are compared between the two real-ear analyzers (Verifit SL subtracted from the SoundTracker SL compared to the 6500 SL subtracted from the SoundTracker SL), small mean differences (≤2 dB) were also noted. A statistically significant difference, however, was reported at 2000 Hz. Again, this result may not be clinically significant, but this difference was as great as 5.9 dB, which could be of clinical significance. This again, however, may be an outlier as only five of the measures were ≥5 dB. This difference may be due to the different signals utilized for the REAR measurements as the pink noise used in the Verifit provides a flat frequency response from 250 to 8000 Hz, whereas the speech-weighted composite noise used in the 6500 begins to attenuate after 2000 Hz.

The test-retest differences of the measures for SoundTracker REAR (Fig. 9A), Verifit in situ (Fig. 9B), Verifit REAR (Fig. 9C), 6500 in situ (Fig. 9D), and 6500 REAR (Fig. 9E) are displayed in Figure 9 for the frequency of differences of 0 to 2 dB. As can be seen, 90% or more of the differences between test-retest measurements were ≤2 dB, except for 2000 and 4000 Hz for 6500 REAR.

Table 1. Cohen's d for the Differences between the Estimated SL for SoundTracker and the Measured SL of the Audioscan Verifit and Frye 6500

Comparison	Frequency	Cohen's d
SoundTracker and Audioscan Verifit	500 Hz	−0.4
	1000 Hz	0.2
	2000 Hz	0.3
	4000 Hz	0.2
SoundTracker and Frye 6500	500 Hz	0.3
	1000 Hz	0.3
	2000 Hz	−0.2
	4000 Hz	0.3

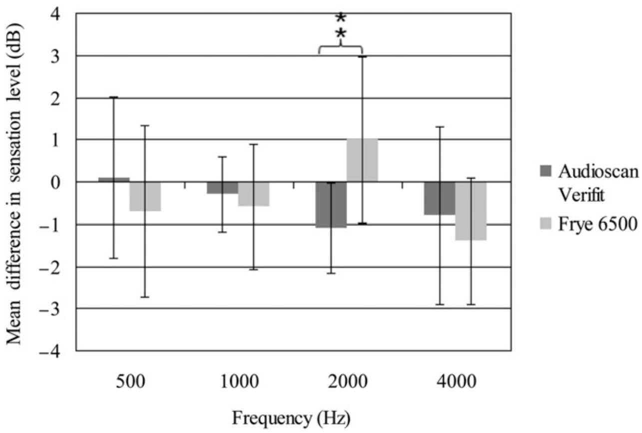

Figure 8. Mean measured average differences in SL between the Verifit (Verifit SL subtracted from the SoundTracker SL) compared to the 6500 (6500 SL subtracted from the SoundTracker SL). A negative value indicates great SL output for the respective real-ear analyzer compared to SoundTracker. $^{**}p < 0.01$.

There were a few outliers, with the largest being no greater than 7 dB. For the remaining test-retest differences for SoundTracker REAR, nine measures were within 3 dB, four within 4 dB, two within 5 dB, one within 6 dB, and one within 7 dB. For the Verifit in situ, two measures were within 3 dB, two within 4 dB, and three within 5 dB, and for REAR, 12 measures were within 3 dB, three within 4 dB, and one within 7 dB. For the 6500, all measures for in situ were within 2 dB, and for REAR, ten measures were within 3 dB, four within 4 dB, five within 5 dB, and three within 7 dB. In comparison, Valente et al (1991) examined the test-retest reliability of real-ear unaided responses (REURs) using the Frye 6500. This study examined test-retest reliability of the REUR with the same examiner performing the procedure approximately 2 wk later. The overall peak level and specific frequencies were examined. Results revealed mean test-retest reliability was within 1 dB from 250 to 4000 Hz. The Valente et al (1991) results showing a ≤1 dB difference are slightly better than the results of this study but are still in close agreement with SoundTracker test-retest reliability results.

While results from this study report that SoundTracker can accurately estimate SL using the outlined procedures, there are some limitations to this study and its application to clinical use:

a. SoundTracker is only available for use with Widex hearing aids. Therefore, this tool cannot be used with any other manufacturer's hearing aids. While other manufacturer's offer in-situ measures through their fitting software, it is unknown how accurate these other software programs are.
b. Only patients with a mild to moderately severe sensorineural hearing loss (>30 dB HL below 1000 Hz and ≤70 dB HL to 4000 Hz) using conventional earmolds were evaluated. It is unknown whether measures using subjects with a different magnitude of hearing loss than those used in this study or with different hearing aid configurations, such as open-fit hearing aids, would yield similar results.
c. The noise floor of the test room (which met the ANSI S3.1-1999 [R2008] standard [ANSI, 2003] for open-ear listening), the fan noise from the computer, and noise floor of the microphones of the real-ear analyzers prevented stable measures of Sensogram thresholds measured with the real-ear analyzers if Sensogram thresholds were <45 dB HL at 500 Hz, <35 dB HL at 1000 Hz and 2000 Hz, and <50 dB HL at 4000 Hz. If hearing thresholds were better than these cutoff values, Sensogram thresholds could not be measured with the real-ear analyzers utilized in this study due to limitations of the real-ear analyzers and the noise floor of the room. This could be problematic particularly for patients with open-fit hearing aids who require minimal amplification as this methodology for measuring SL would be difficult to determine due to external limitations of the real-ear analyzers and noise floor of the room.
d. Only four test frequencies of a possible 15 were evaluated, and it is unknown whether the accuracy of ≤2 dB would apply to the other frequencies as well.
e. Precise measurements for in-situ threshold measures were often difficult to obtain with the 6500 as the visual output was not as stable compared to using the Verifit. The software of the 6500 makes it more difficult for the user to freeze and store the measure as is possible with the Verifit. This difference in the equipment used in the present study resulted in the measures of in-situ thresholds to be more difficult and time-consuming when using the 6500 than with the Verifit. When the test-retest data are examined, however, both real-ear analyzers were within 2 dB greater than 90% of the time, with the 6500 showing lower test-retest differences than the Verifit despite this measurement limitation.

Finally, it is important to remind the reader that the authors *are not* advocating using SoundTracker as a substitution for real-ear measures. While SoundTracker could be helpful as a counseling tool to visually illustrate the benefit of amplification, SoundTracker does not allow the audiologist to determine if the amount of amplification is appropriate or inappropriate as no prescriptive target is available such as the National

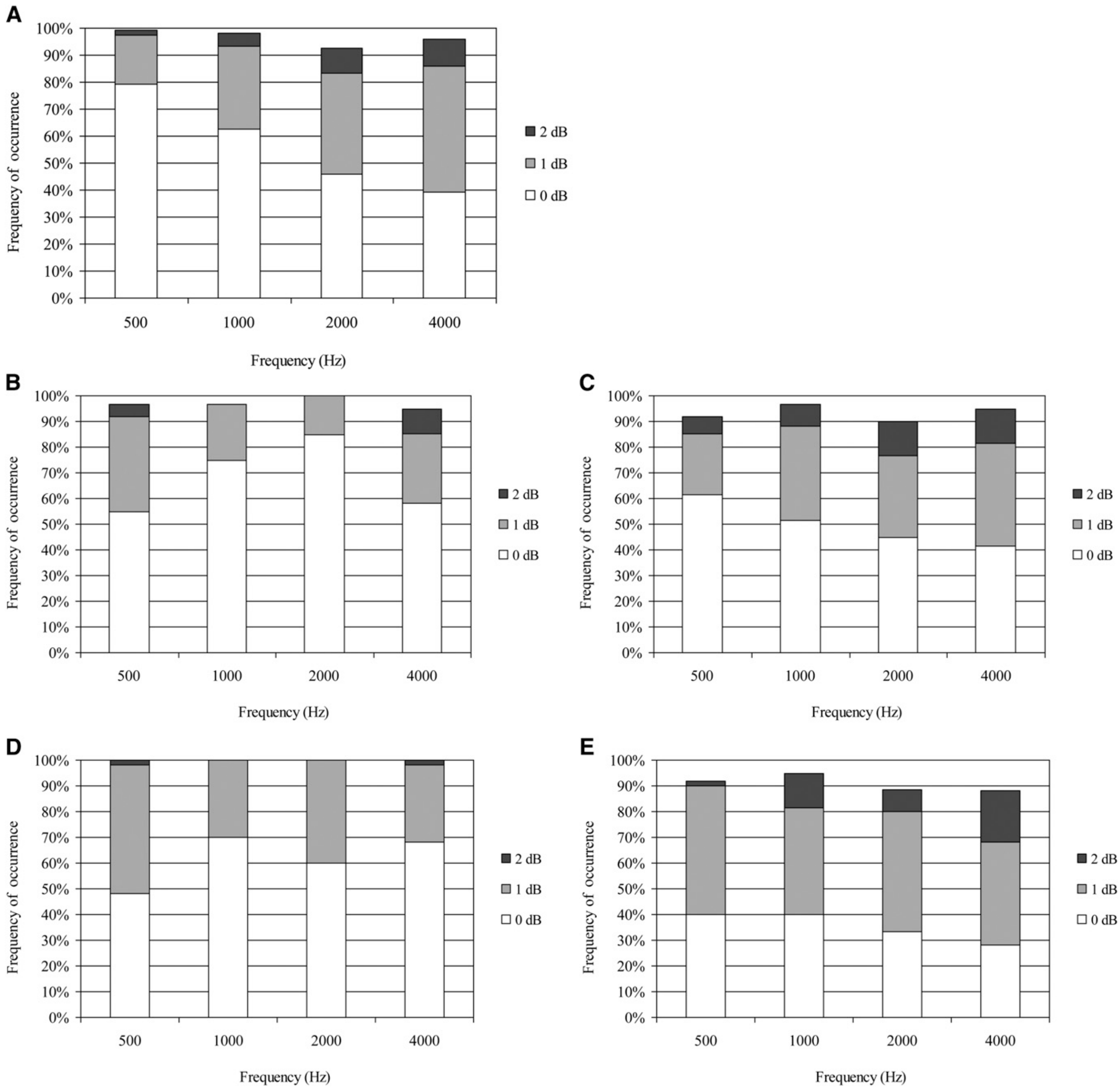

Figure 9. Frequency distribution of test-retest differences of 0, 1, or 2 dB for SoundTracker REAR *(A),* Verifit in situ *(B),* Verifit REAR *(C),* 6500 in situ *(D),* and 6500 REAR *(E).*

Acoustic Laboratories' nonlinear fitting procedure, version 1 (Byrne et al, 2001). There is also no standardized signal available in SoundTracker to adjust the hearing aid to achieve an appropriate degree of amplification, such as a speech-weighted composite signal. If external signals, such as a spouse's or audiologist's voice were used, there is no ability to control the intertalker differences such as the overall level of the voice, spectrum, and differences within and between gender to determine the accuracy of settings for a soft, medium, and loud input signal. Currently, therefore, the only acceptable method for verifying hearing aid performance, as recommended in the American Academy of Audiology guideline for fitting hearing aids to adult patients, is using real-ear measures (Valente et al, 2006). SoundTracker could, however, be used to counsel patients on what sounds are inaudible by examining the unaided bars and whether they are above the patient's in-situ thresholds. Discussion on talker distance, level of voice, and the differences between male and female voices could also be demonstrated by showing how these variables can impact audibility when a patient is unaided. Then the aided bars could be displayed and the patient and family members could see how the hearing aids provide benefit by having the addition of the aided gain, which will bring sounds above the patient's in-situ thresholds. Limitations of hearing aids could be discussed, such as demonstrating how talking from another room still makes hearing difficult for a patient even with hearing aids. This could also facilitate counseling patients and their families on using good communication strategies, such as facing the listener and using a slow, clear speaking rate.

CONCLUSIONS

Mean differences in the estimated SL of SoundTracker compared to the measured SL of the Verifit and 6500 were ≤2 dB in 84.4% of the 160 individual measurements. When mean differences in measured SL were compared between the two real-ear analyzers, differences were also ≤2 dB. SoundTracker, when used with Widex hearing aids, could be used clinically as a counseling tool for patients and families illustrating the benefit of amplification relative to unaided performance. While SoundTracker's ability to accurately estimate a patient's SL was found to be in good agreement with the two real-ear analyzers used in the present study, there are limitations in how SoundTracker can be used clinically. These limitations are that (a) only Widex hearing aids can be used; (b) a limited magnitude of hearing loss was examined, and it is unknown if the same degree of accuracy would be maintained for other hearing levels and hearing aid configurations such as open-fit hearing aids; (c) there is no standardized signal, and it is uncertain if accuracy would change with different signals; (d) only four test frequencies were examined, and accuracy of other frequencies is unknown; and (e) the noise floor of the real-ear analyzer and room measurements may impact Sensogram measurements. Future studies should focus on examining different magnitudes and configurations of hearing loss and different hearing aid couplings, such as an open-fit hearing aid. Again, it is important to emphasize that while SoundTracker has been shown to be accurate in estimating SL within approximately ≤2 dB in 84% of the measures in the present study and, therefore, would make an excellent counseling tool, SoundTracker cannot be advocated as a replacement for real-ear verification because there is no guidance provided on how much SL is appropriate or inappropriate (i.e., prescriptive targets), and there is no standardized signal.

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